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UH-1 BALLISTIC AND BIRD IMPACT TEST STUDY

Wilson C. McDonald, et al

Goodyear Aerospace Corporation

Prepared for:

Army Materials and Mechanics Research Center

April 1975

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# Production Engineering Measures Program
# Manufacturing Methods and Technology

# UH-1 BALLISTIC AND BIRD IMPACT TEST STUDY

April 1975

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Goodyear Aerospace Corporation

Arizona Division

Litchfield Park, Arizona 85340

Final Report

Contract Number DAAG46-75-C-0005

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| Composites | As-cast acrylic | Cast-in-place interlayer (CIP) |
| Polycarbonate | Abrasion coating | Acrylics |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program concerns the ballistic and bird impact testing of UH-1 windshields of three different designs. These designs included an acrylic windshield (which was used as the standard), a monolithic polycarbonate windshield with abrasion coating on both surfaces, and a glass-plastic composite using chemically strengthened glass (Chemcor) as the other glass ply.

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## FOREWORD

This is the final technical report on a program conducted to assess the bird impact resistance and backside spalling characteristics accompanying ballistic penetration of two types of prototype construction UH-1 windshields. The standard acrylic UH-1 windshield was included in the program for comparison.

The program was performed by Goodyear Aerospace Corporation, Arizona Division, Litchfield Park, Arizona, under Contract DAAG46-75-C-0005. The work was done for the Army Materials and Mechanics Research Center, Watertown, Massachusetts.

The Technical Supervisor for this contract is Mr. J. Plumer.

Goodyear Aerospace has assigned GERA-2075 as a secondary number to this report. W.C. McDonald is the project engineer for Goodyear Aerospace Corporation. This report was submitted by the author in February 1975 for publication, and covers work conducted between 16 August 1974 and 16 January 1975.

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## SECTION I -

## INTRODUCTION

1. GENERAL

In the spring of 1973, the U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts, issued a contract (DAAG46-73-C-0074) to Goodyear Aerospace Corporation, Litchfield Park, Arizona, to fabricate two types of improved scratch- and spall-resistant windshields. These windshields included a glass-plastic concept and a monolithic polycarbonate with abrasion coating on both faces. These parts were tested at Fort Rucker, Alabama, and demonstrated that with state-of-the-art materials, substantially improved scratch-resistant helicopter windshields could be produced. Since field experience has shown that replacement of helicopter windshields is necessitated mainly by abrasion, this effort was considered extremely important.

2. PROGRAM SCOPE AND OBJECTIVES

Contract DAAG46-75-C-0005 was issued as a continuing effort to determine how these improved abrasion-resistant helicopter windshields would react under ballistic and bird impact. Good data have been lacking in these areas, and this contract was initiated to fill in some of the information gaps that existed on helicopter windshields.

The work effort was conducted at the Litchfield Park, Arizona, plant where both fabrication and test facilities are located. The program was broken down into the following efforts:

1. Monolithic polycarbonate windshield -

Two 1/4-inch monolithic polycarbonate windshields were fabricated with an abrasion coating (Abcite)[a] on both the inner and outer surfaces. The windshield configuration, including edge attachment, conformed to Bell Helicopter drawing P/N 204-030-666-44. A third part previously fabricated by Goodyear Aerospace was supplied by the Army to provide the remaining part needed for the test program. The parts were fabricated using SL 2000-111 grade press-polished polycarbonate.

2. Glass-plastic windshields -

Two composite glass-plastic windshields were fabricated to the standard UH-1 shape. The third unit previously built by Goodyear Aerospace was furnished by the Army for inclusion in the test program.

3. Standard acrylic windshields -

The Army furnished for the program three standard as-cast acrylic UH-1 windshields (P/N 204-030-666-44) from inventory.

Details of the construction of these test articles are shown in Figure 1. Data collected pertaining to typical weights and optical properties of the test articles are included in Table 1.

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[a]TM, E.I. DuPont de Nemours, Inc., Wilmington, Delaware.

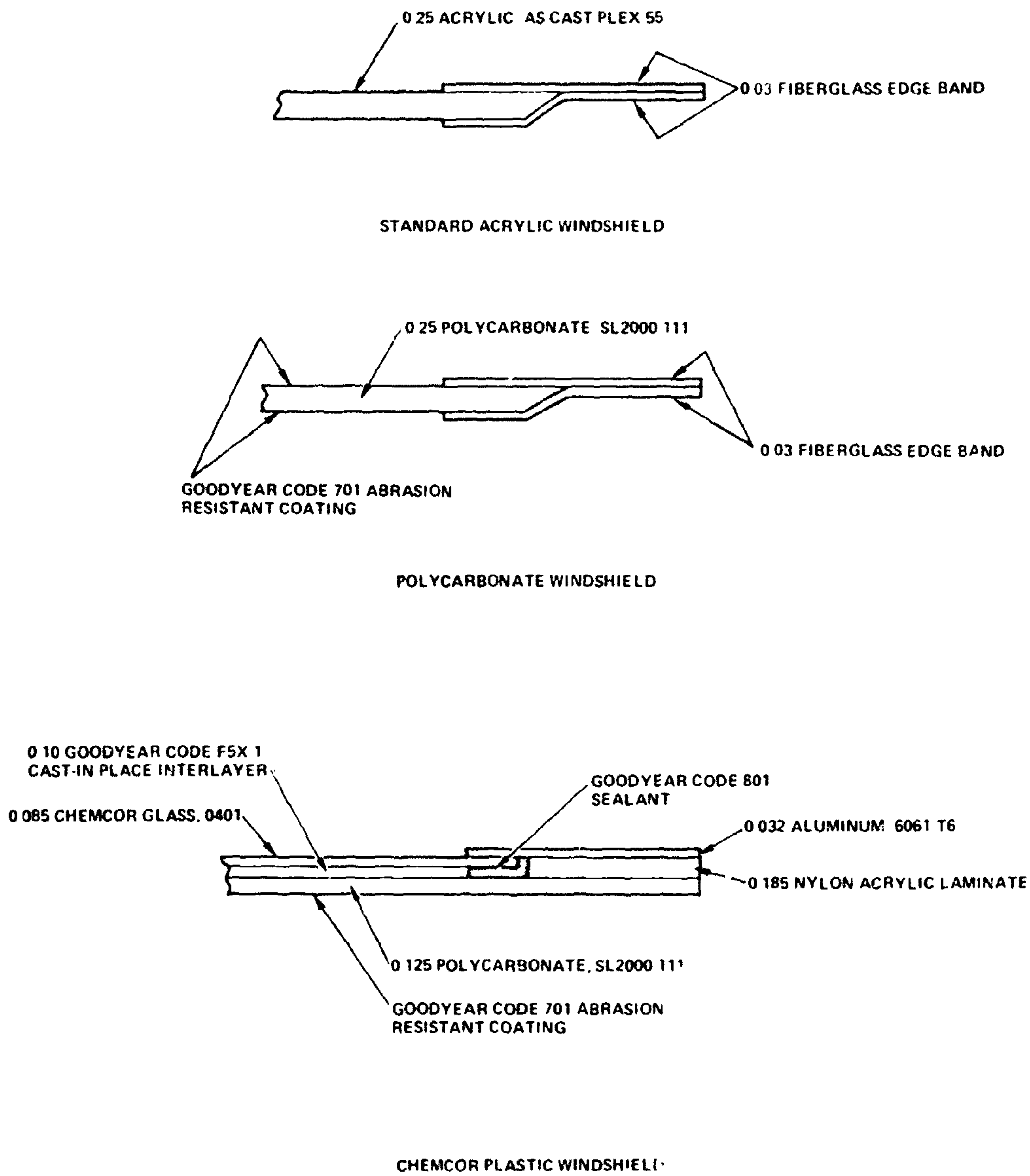


Figure 1 - UH-1 Windshield Test Constructions

## TABLE 1 - UH-1 WINDSHIELD TEST DATA

| Windshield type | Total weight (lb) | Luminous transmittance (percent) | Haze (percent) |
|---|---|---|---|
| Standard acrylic | 12.7 | 91.5 | 1.0 |
| Polycarbonate | 13.8 | 89.0 | 1.0 |
| Chemcor*-plastic | 24.[illegible] | 90.0 | 0.5 |

*TM, Corning Glass Works, Corning, N.Y. 14830.

## SECTION II -

## BALLISTIC TESTING

### 1. GENERAL

Ballistic testing was conducted on one each of the three windshield types being evaluated. Each windshield was subjected to three ballistic strikes using caliber .30 ball M2 projectiles at a velocity approximating 100-yard range. The strikes were well above the defeat threshold velocity for any of the three windshield constructions tested.

The tests were designed to measure the quantity and nature of back side spalling resulting from such penetrations. An assessment of post-hit structural integrity and visibility for each windshield construction was also sought.

### 2. TEST PROCEDURE

Each windshield tested was mounted in the UH-1 structure in a manner approximating a normal installation for this article. A transparent plastic box was mounted directly behind the windshield. This box was utilized to apply a vacuum to the aft side of the windshield during test to simulate aerodynamic loading imposed at the aircraft redline speed of 120 knots (see Figure 2). The calculated loading for the windshield at 120 knots was 0.328 psi.

The quantity and nature of the ballistic spall generated by the penetration of each windshield were recorded in two ways. A witness sheet of 0.020-inch-thick 2024 T3 aluminum alloy was used to record the dispersion pattern and relative lethality of the spall particles.

Figure 2 - UH-1 Windshield Ballistic Test Structure with Pressure Box
(Shown without Witness Sheet or Back Installed)

The witness sheet was positioned within the pressure box as a vertically oriented, peripherally supported diaphragm located at the pilot's nominal eye position (aircraft station 53.0). A spall particle having sufficient remaining energy to pierce the witness sheet material placed parallel to and six inches behind the target is normally expected to produce lethal damage or its equivalent from a variety of mass-velocity combinations.[a]

The witness sheet positioned at station 53.0 was approximately 28 inches behind the impact area of each windshield. This location was selected since it approximated the pilot's position and provided visual access to the back side of the windshield for the high-speed cameras which provided the second source of spall documentation. Two high-speed cameras were used to record the overall windshield response and characteristics of any spall generated.

One high-speed camera operating at 3,000 frames per second was used to view the front side of the windshield. The back side of the windshield was monitored with a 11,000-frame-per-second high-speed camera during each test firing. One additional camera operating at a standard framing rate was used to document the test setup and individual firing sequences. A schematic of the ballistic test setup used in this evaluation is shown in Figure 3. The actual test setup is illustrated in Figure 4.

Each windshield was impacted with a total of three caliber .30 ball M2 projectiles which had been reloaded to simulate the remaining velocity for this round at 100-yard range (2550 ft/s). A centrally located equilateral triangle shot placement pattern was used for all three windshields tested. Measurement of the post-test articles showed that the actual center-to-center shot spacings ranged from 6.75 to 9.00 inches.

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[a]Watertown Arsenal Laboratories Monograph Series Report WAL MS-12, "Ballistic Concepts Employed in Testing Lightweight Armor," 5 October 1959.

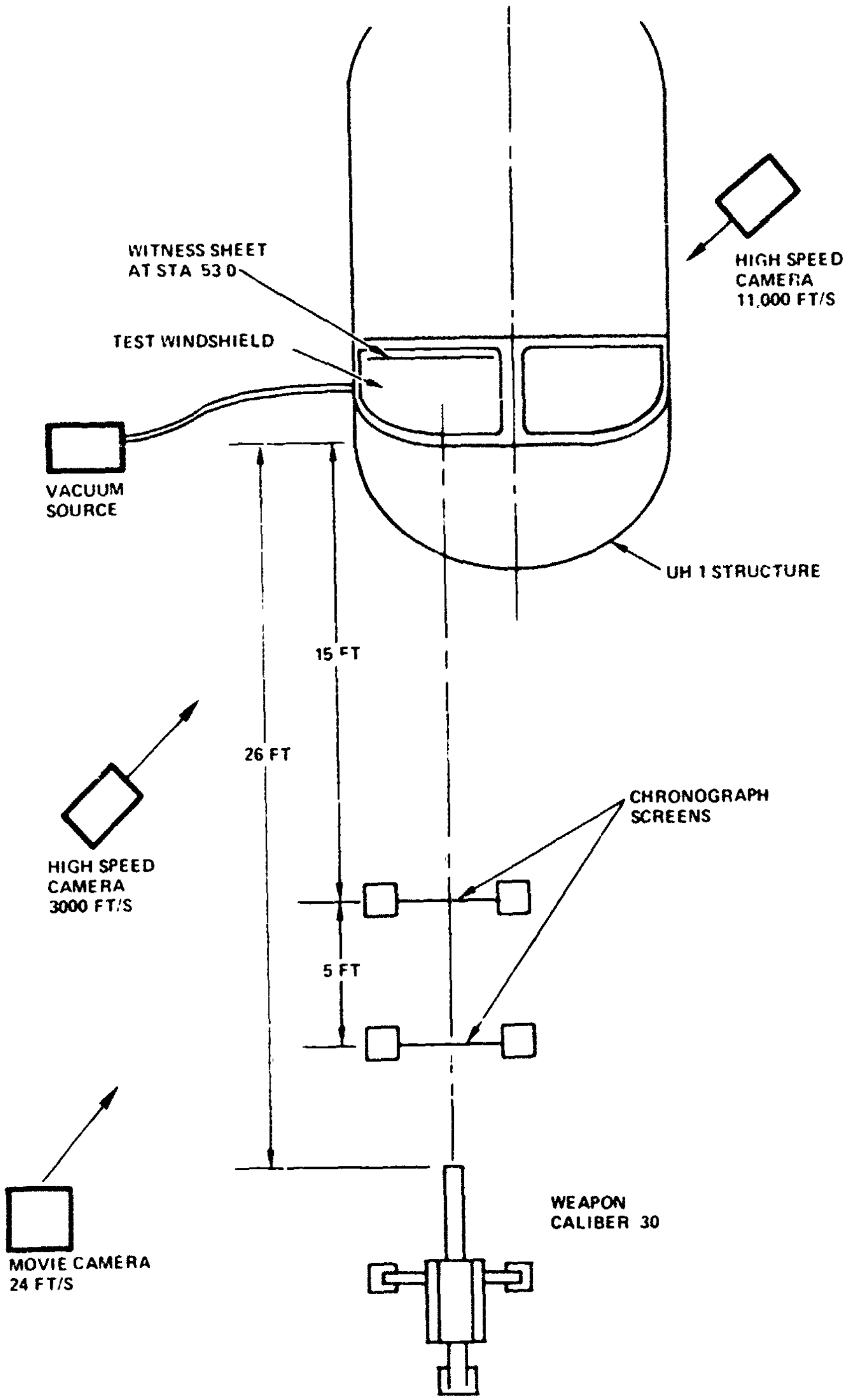



Figure 3 - Ballistic Test Setup, Schematic Plan View

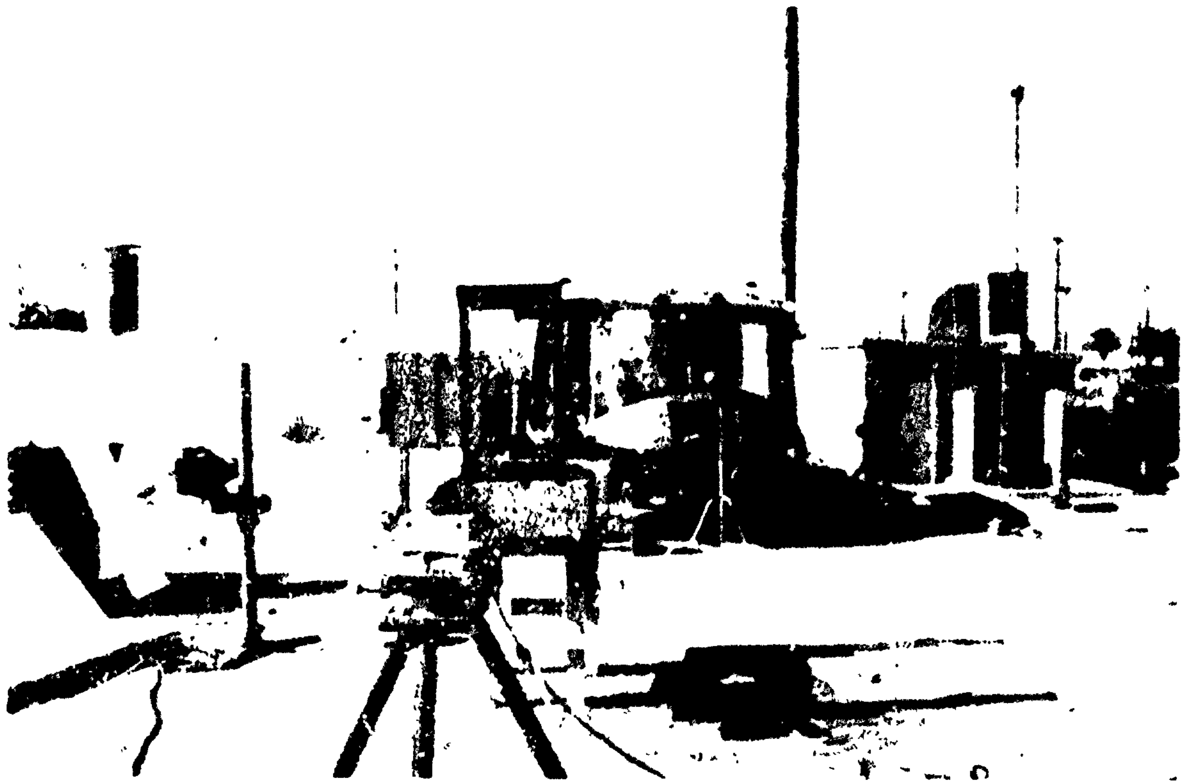


Figure 4 - Ballistic Test Setup, UH-1 Windshields

## 3. TEST RESULTS

The back side spalling characteristics of each type of windshield tested are summarized in Table 2. Photographs of the expended test articles, Figures 5, 6, and 7, illustrate the extent of overall damage resulting from the ballistic penetrations. Much of the overall glass fracture in the Chemcor-plastic windshield was incurred during post-test removal from the aircraft structure and subsequent handling. More accurate display of the post-hit visibility through this article is shown in the motion picture documentation. The extent of post-hit crack propagation which would occur in flight as a result of aircraft vibration and flight loads imposed is unknown.

Additional details of the comparative material behavior are shown in the front and back side closeup photographs, Figures 8 through 13. The witness sheets from each test are shown in Figures 14, 15, and 16. Spall data reported for each test excluded the single perforation of the witness sheet caused by the bulk of the projectile.

## 4. ANALYSIS OF SPALL CHARACTERISTICS

Typical back side spall particles collected following one ballistic penetration of each type of windshield are illustrated in Figure 17. The particles from the Chemcor-plastic composite which perforated the witness sheet were not collected and therefore are not included in Figure 17.

After both the physical evidence and photographic data collected were reviewed, the following summary of performance was prepared:

1. Chemcor-plastic composite windshield -

   The ballistic penetration of this windshield generated many spall particles, a number of which had potentially lethal penetrating characteristics. These penetrating particles are probably both glass and bullet fragments.

TABLE 2 - WINDSHIELD BACK SIDE SPALLING BALLISTIC TEST DATA

| Test article | Round no. | Test temperature (deg F) | Velocity (ft/s) | Witness sheet perforations | Witness sheet marks | Maximum dispersion of spall (in.) |
|---|---|---|---|---|---|---|
| P/N 204-030-666-44 | 1 | 70 | 2579 | 0 | 6* | 14.50 |
| UH-1 standard acrylic | 2 | 70 | 2526 | 0 | 2* | 8.75 |
| windshield | 3 | 75 | 2540 | 0 | 2* | 12.75 |
| UH-1 prototype windshield | 1 | 65 | 2566 | 6 | 36 | 10.75 |
| Chemcor-plastic composite | 2 | 65 | 2540 | 10 | 65 | 18.00 |
| | 3 | 65 | 2540 | 10 | 32 | 13.75 |
| UH-1 prototype windshield | 1 | 65 | 2632 | 0 | 0 | - |
| Monolithic polycarbonate | 2 | 75 | 2500 | 0 | 0 | - |
| | 3 | 75 | 2500 | 0 | 0 | - |

*Spall particles were very widely dispersed, and many did not strike the witness sheet.

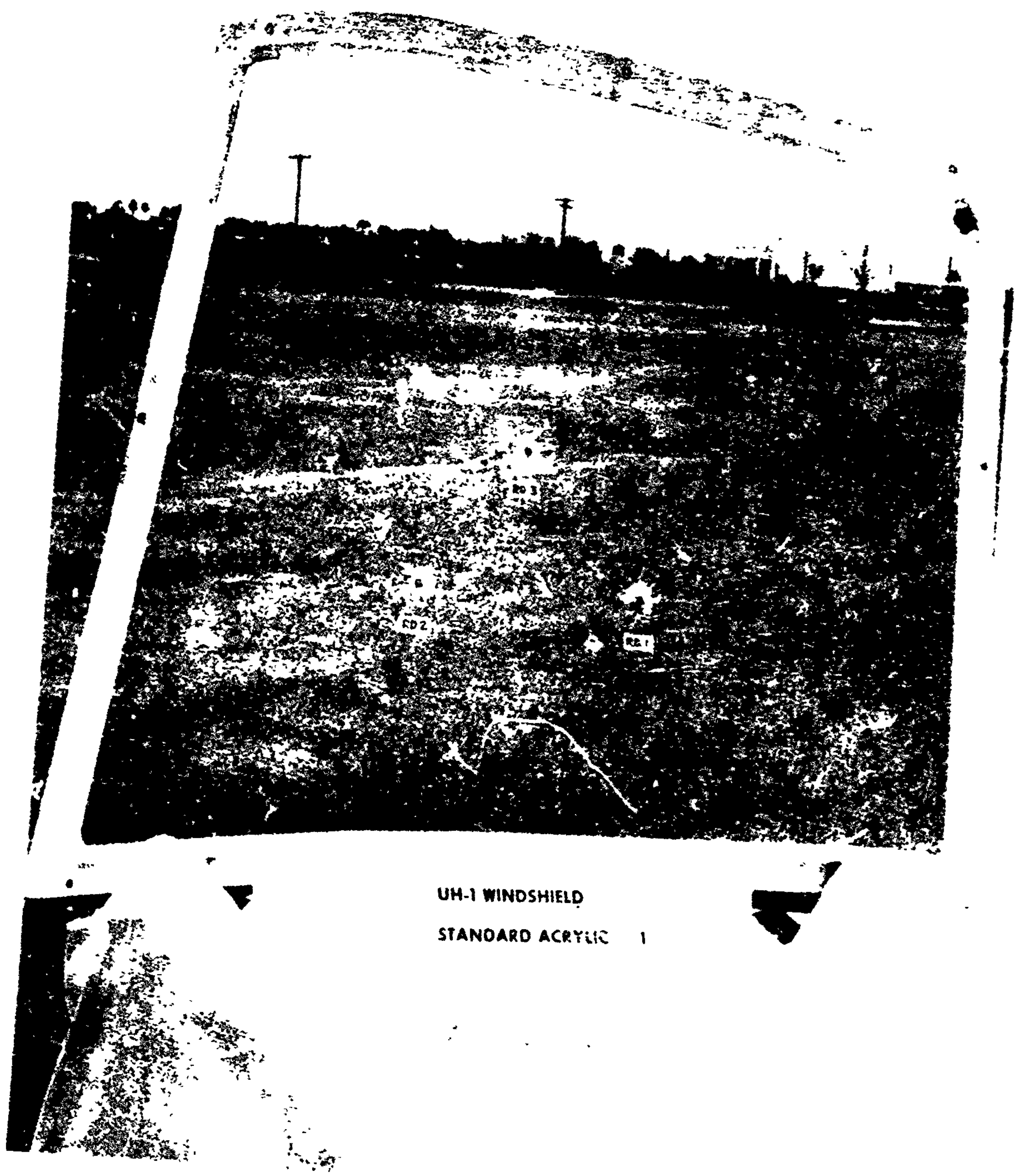



Figure 5 - UH-1 Standard Acrylic Windsnield, Ballistic Test Article, Post-Test Display

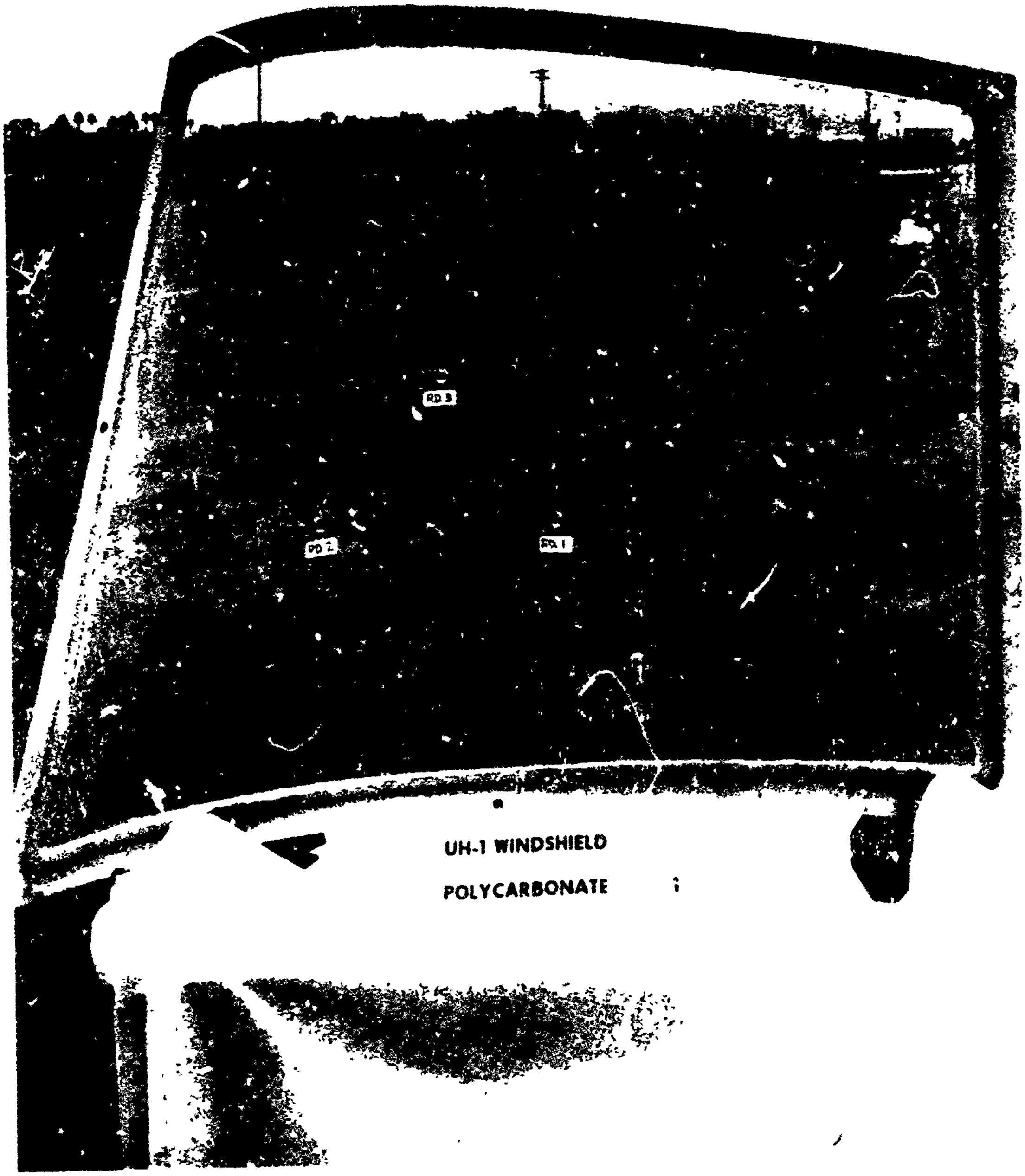



Figure 6 - UH-1 Polycarbonate Windshield, Ballistic Test Article, Post-Test Display

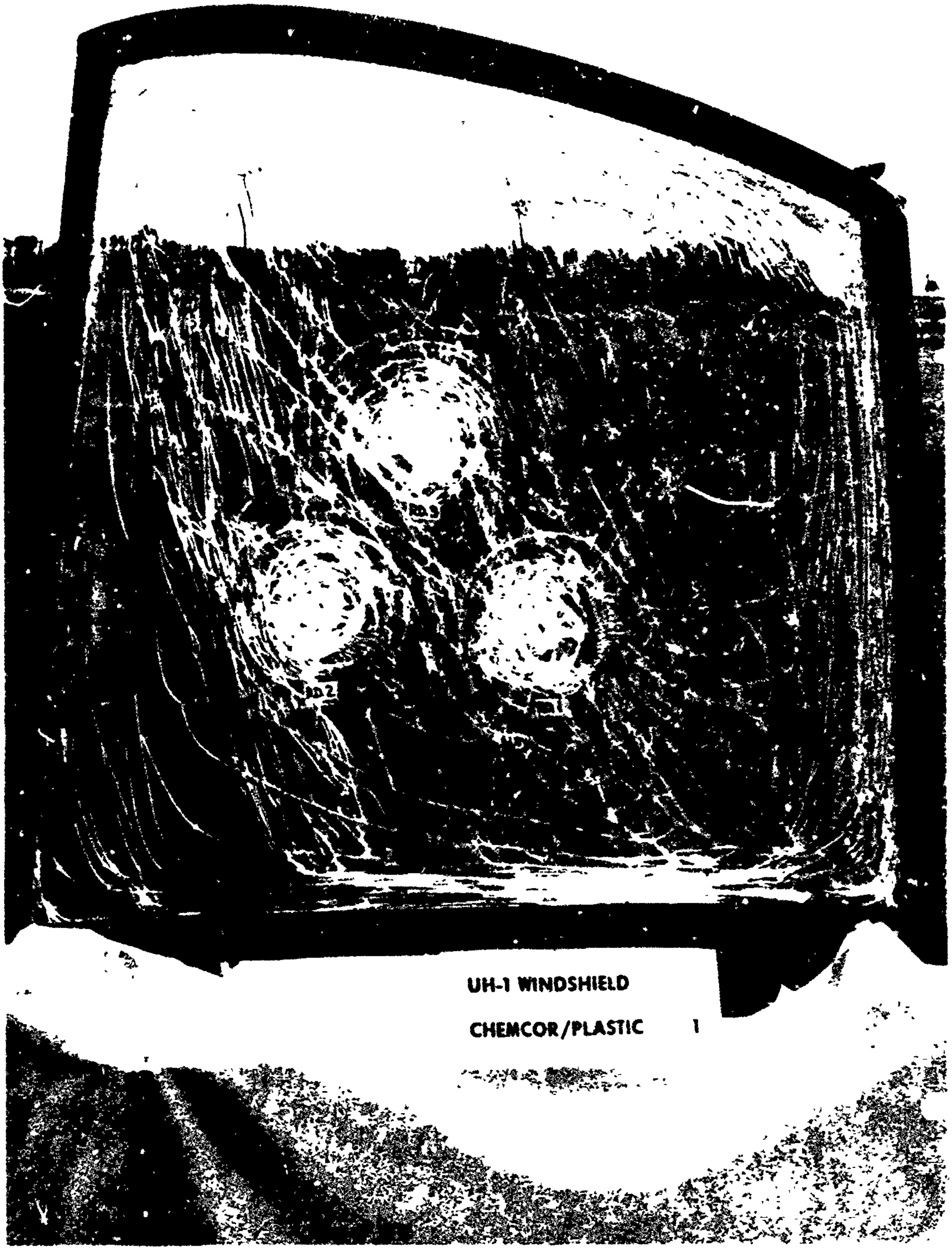



Figure 7 - UH-1 Chemcor-Plastic Windshield, Ballistic Test Article, Post-Test Display

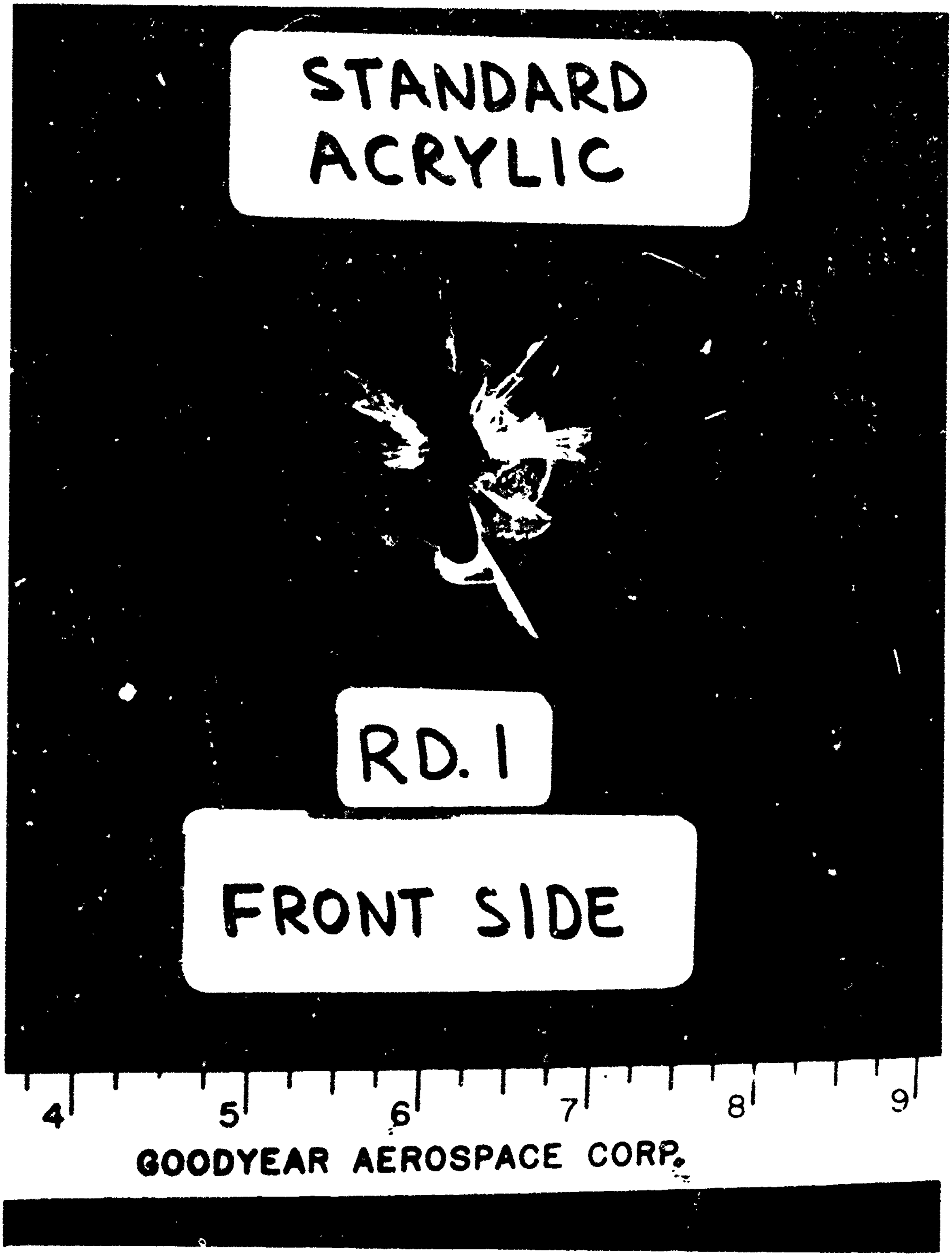



Figure 8 - UH-1 Standard Acrylic Windshield Ballistic Penetration, Front Side Detail

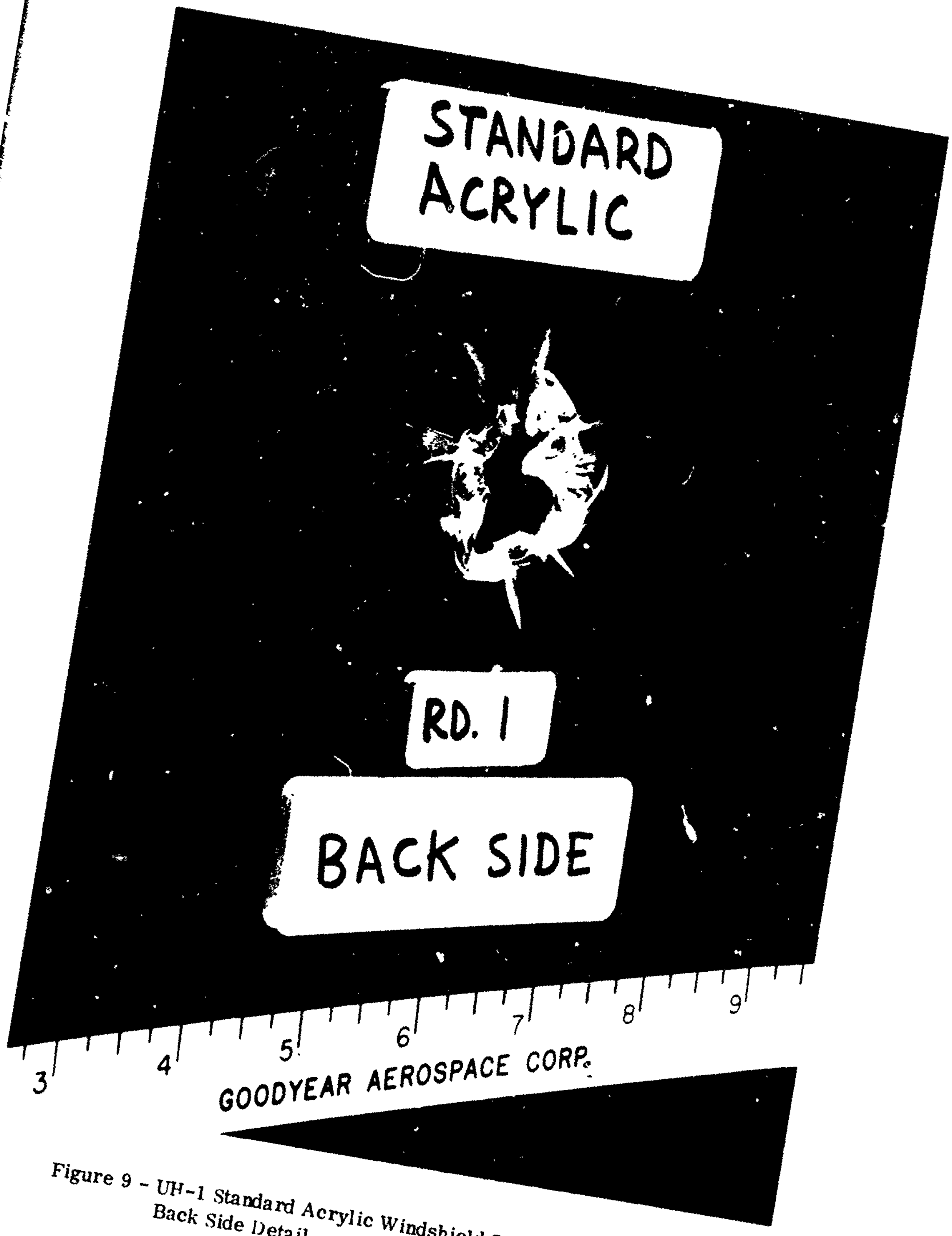



Figure 9 - UH-1 Standard Acrylic Windshield Ballistic Penetration, Back Side Detail

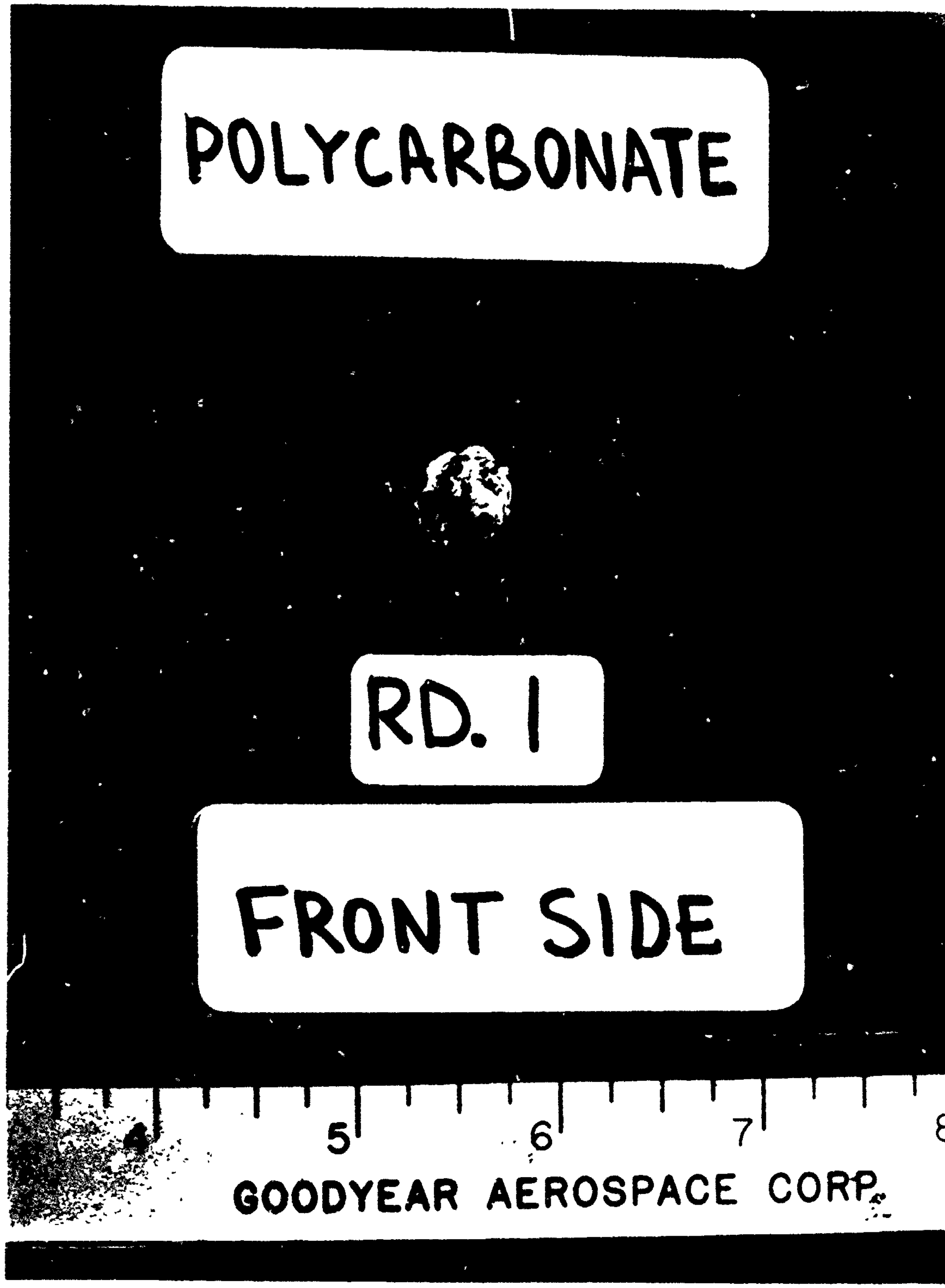



Figure 10 - UH-1 Polycarbonate Windshield Ballistic Penetration, Front Side Detail

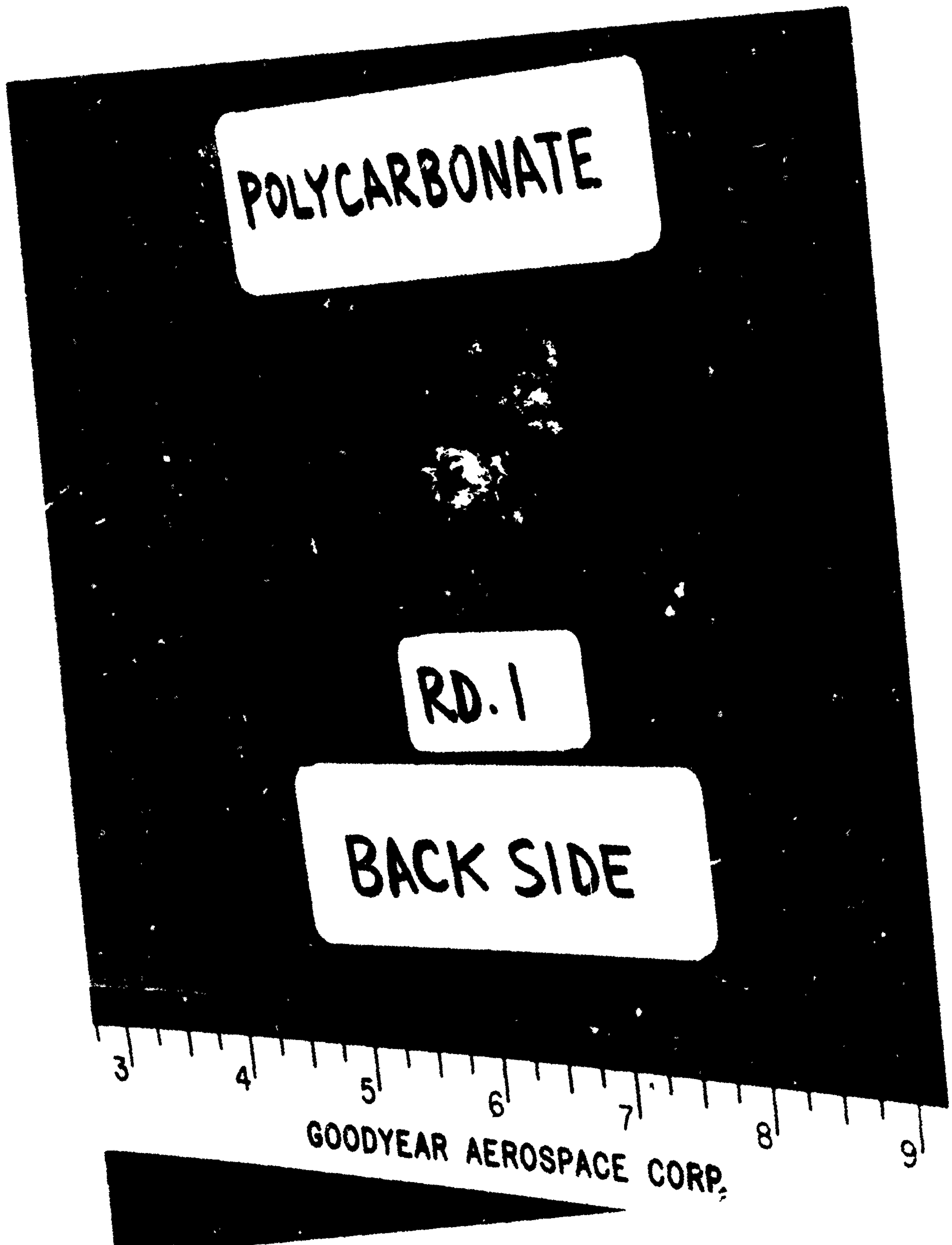



Figure 11 - UH-1 Polycarbonate Windshield Ballistic Penetration, Back Side Detail

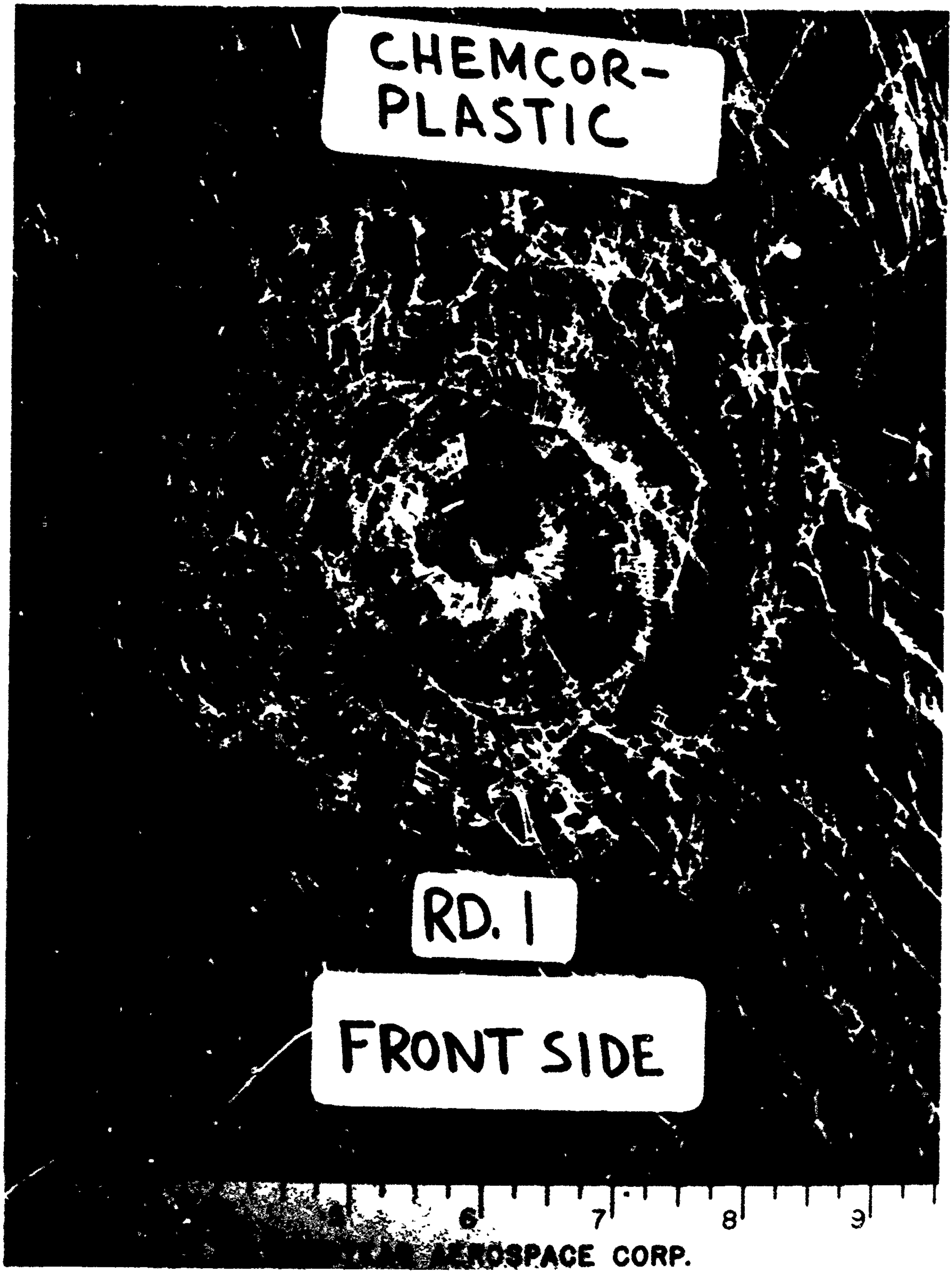



Figure 12 - UH-1 Chemcor-Plastic Windshield Ballistic Penetration, Front Side Detail


Figure 13 - UH-1 Chemcor-Plastic Windshield Ballistic Penetration,
Back Side Detail

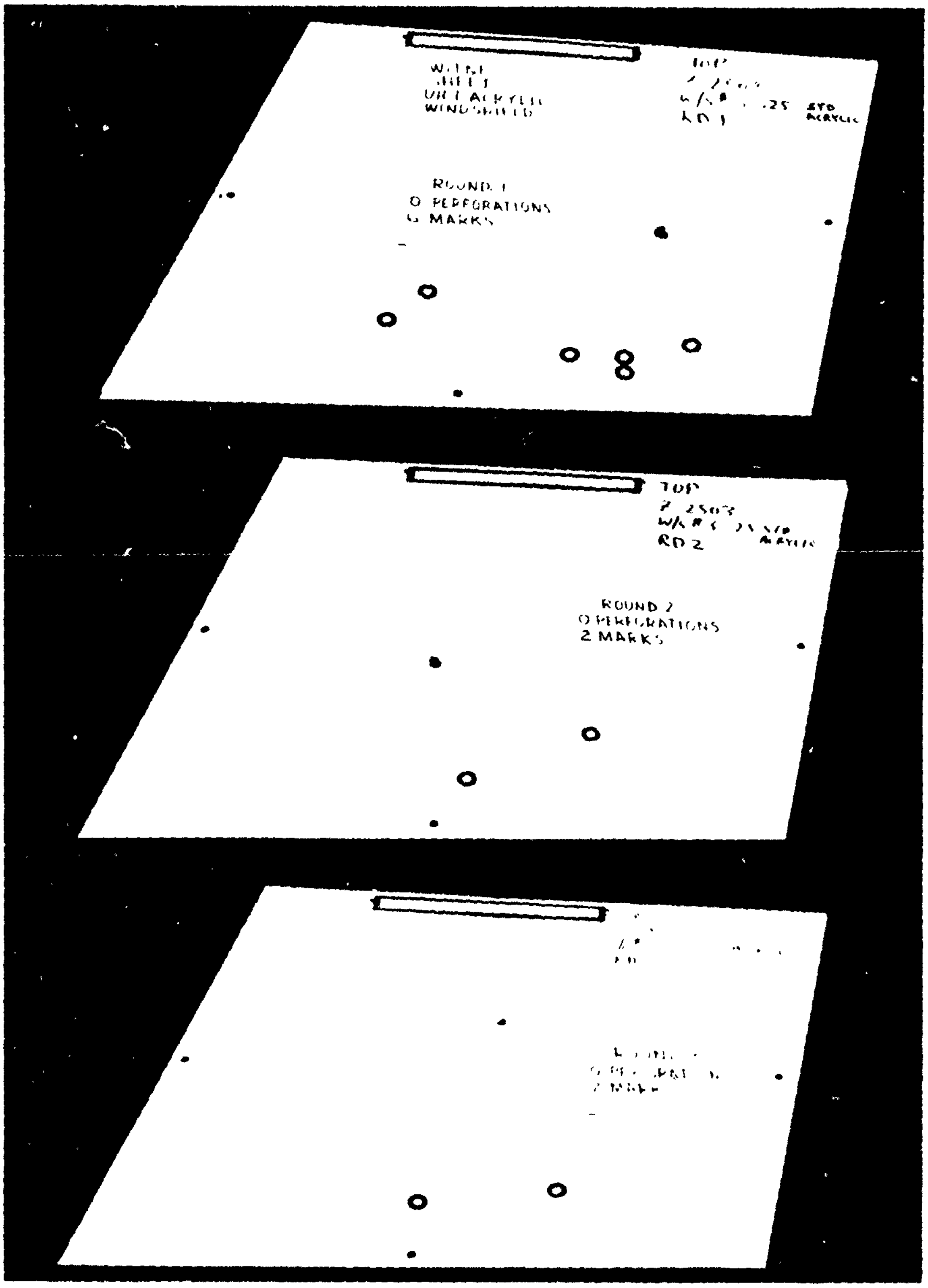


Figure 14 - UH-1 Standard Acrylic Windshield Ballistic Spall Witness Sheets, Post-Test Display

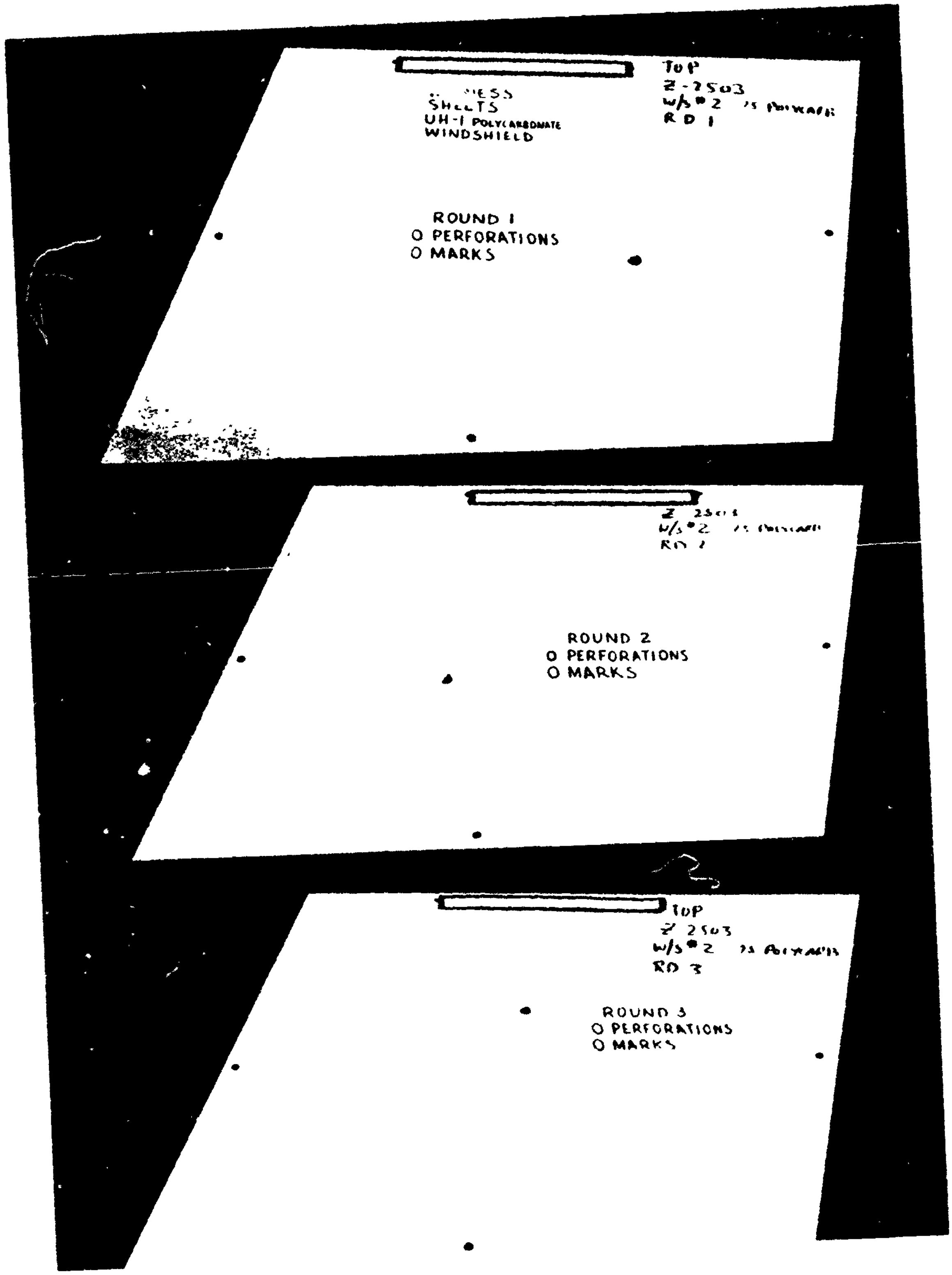



Figure 15 - UH-1 Polycarbonate Windshield Ballistic Spall Witness Sheets, Post-Test Display

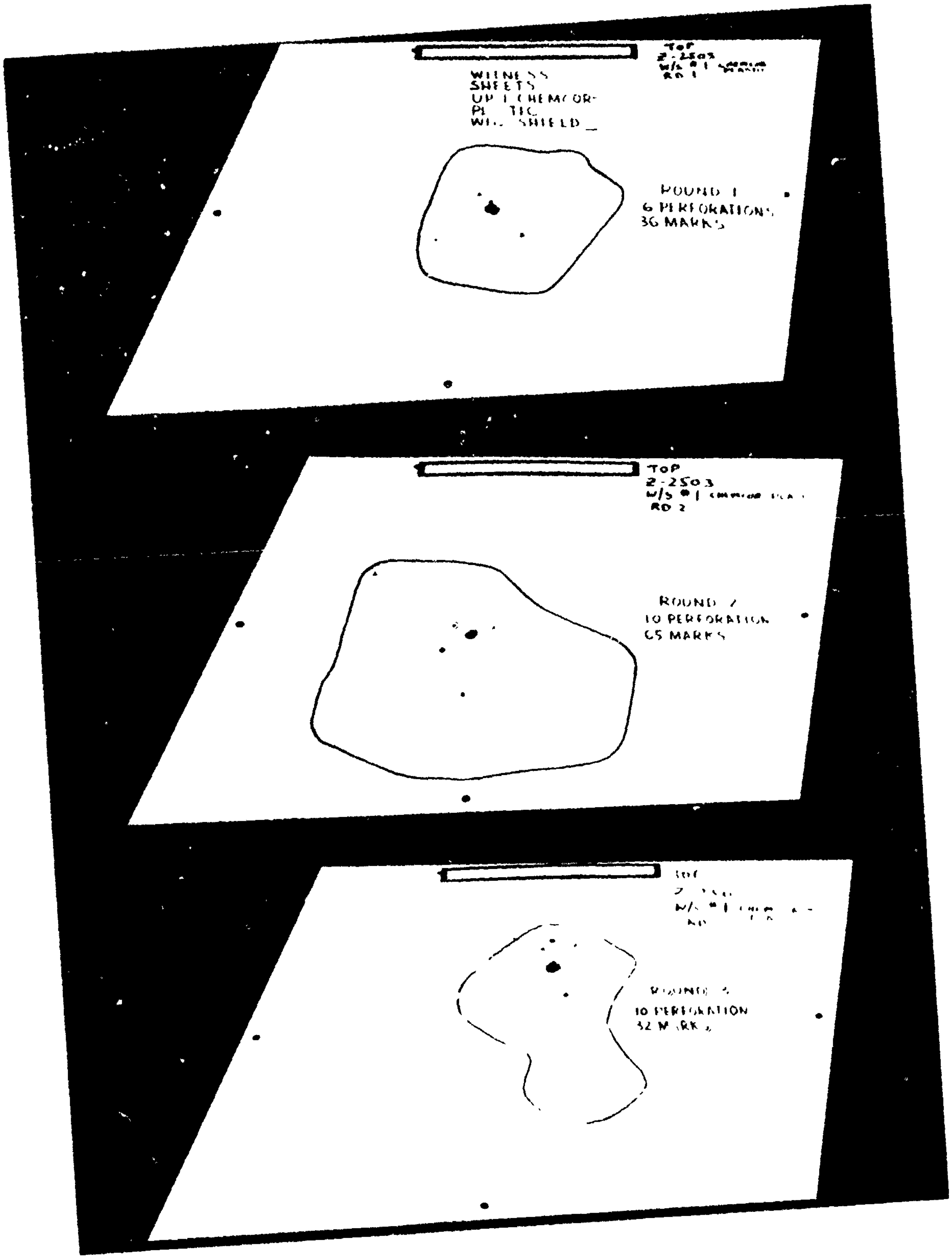
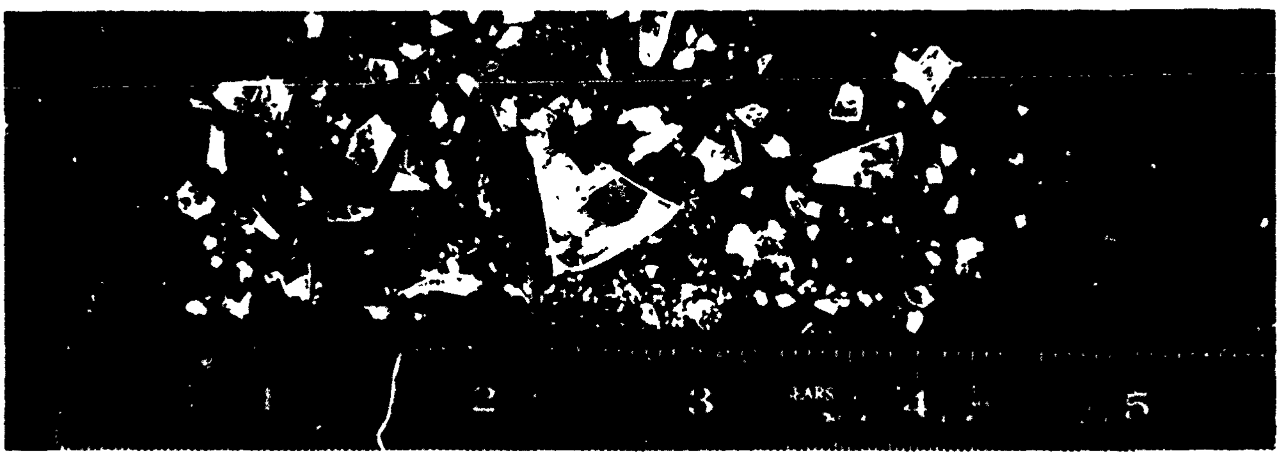
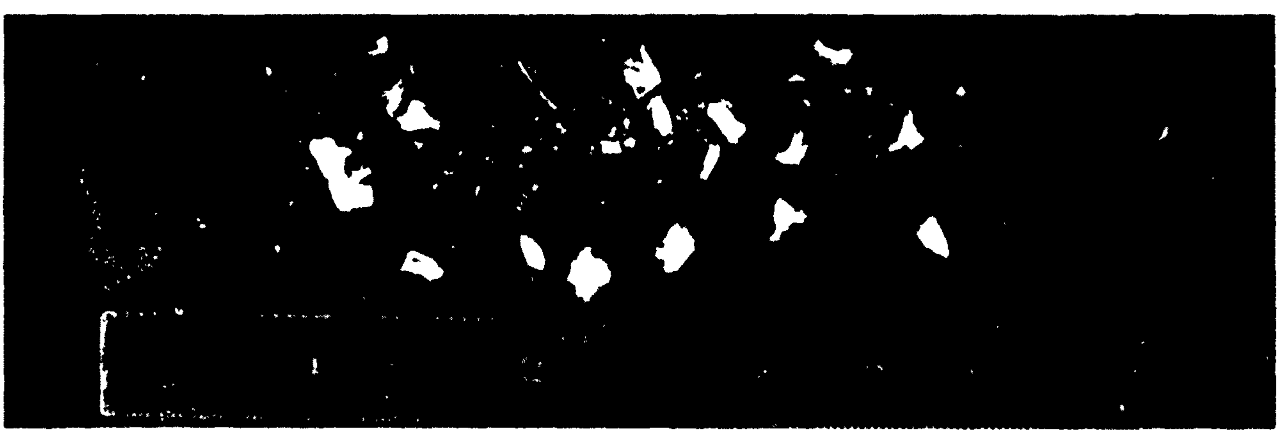



Figure 16 - UH-1 Chemcor-Plastic Windshield Ballistic Spall Witness Sheets, Post-Test Display

0.25 POLYCARBONATE




0.25 AS-CAST PLEX 55 ACRYLIC





CHEMCOR-PLASTIC COMPOSITE

Figure 17 - Typical Ballistic Spall Particles, Single Penetration

The glass outer layer acts to partially break up the projectile. The glass particles and bullet fragments, both having relatively high density, comprise the most hazardous spall. The ductility of the plastic backing ply restricts the dispersion of the spall. The higher-density glass and bullet spall strike the witness sheet at nearly the same instant as the bullet.

This is followed by a cloud of slower, extremely fine particles consisting mostly of glass. The post-hit structural integrity and vision qualities of the windshield appear adequate.

2. Standard acrylic windshield -

The acrylic windshield fractures locally at the impact site. A wide variety of particle sizes is removed and widely dispersed. The acrylic particles are sharp edged and potentially dangerous. The extreme dispersion of the particles caused some of them to miss the witness sheet. None of the particles which struck the witness sheet resulted in a potentially lethal perforation.

The combined factors of quantity, dispersion, and cutting nature of the spall from the acrylic windshield are very unfavorable. The use of helmet visors by the aircrew would add significant eye protection against this type of spall. The disruptive effect on the aircrew flight control created by the spall would be considerable. The post-hit structural integrity and vision qualities for the standard acrylic windshield appear adequate.

3. Monolithic polycarbonate windshield -

The polycarbonate windshield withstood the three ballistic penetrations with a minimum amount of damage and spall.

Ductile penetration without cracking, and wound closure to approximately a 1/8-inch-diameter hole were typical. The back side spalling was limited to a very few small polycarbonate particles. None of these particles marked the witness sheets.

## SECTION III -

## BIRD IMPACT TESTING

### 1. GENERAL

The Goodyear Aerospace bird impact test facility was used to conduct all testing.

The compressed air gun used has a 60-foot-long launch tube with a 6-inch inside diameter barrel. A pressure tank assembly is attached to one end of the launch tube and has a working pressure of 250 psi. The pressure used can be controlled to obtain the bird velocity desired. The four-pound birds used for these tests were loaded in an aluminum sabot which carried them through the barrel. The aluminum container was stopped by a ring at the end of the barrel, while the bird continued to the target.

The velocity of the bird was measured by using counters to measure the time interval between breaking of "start" and "stop" wires. The stop wire is approximately six feet in front of the target window. A UH-1B fuselage was cut in two behind the front door bulkhead so as to maintain the same structural integrity as an unaltered aircraft. This fuselage section was then positioned and anchored in front of the gun where all tests were conducted (see Figure 18).

The same transparent pressure box employed in ballistic testing was used during each bird shot to simulate aerodynamic loading (see Figure 19).

High-speed motion pictures were used to provide the coverage of each test. Cameras operating at 3000 frames per second were used to view the front and side of each windshield during test. The cameras were initiated automatically as a part of the firing sequence. Timed relays were used in the firing circuit to initiate the cameras prior to actuation of the gun.

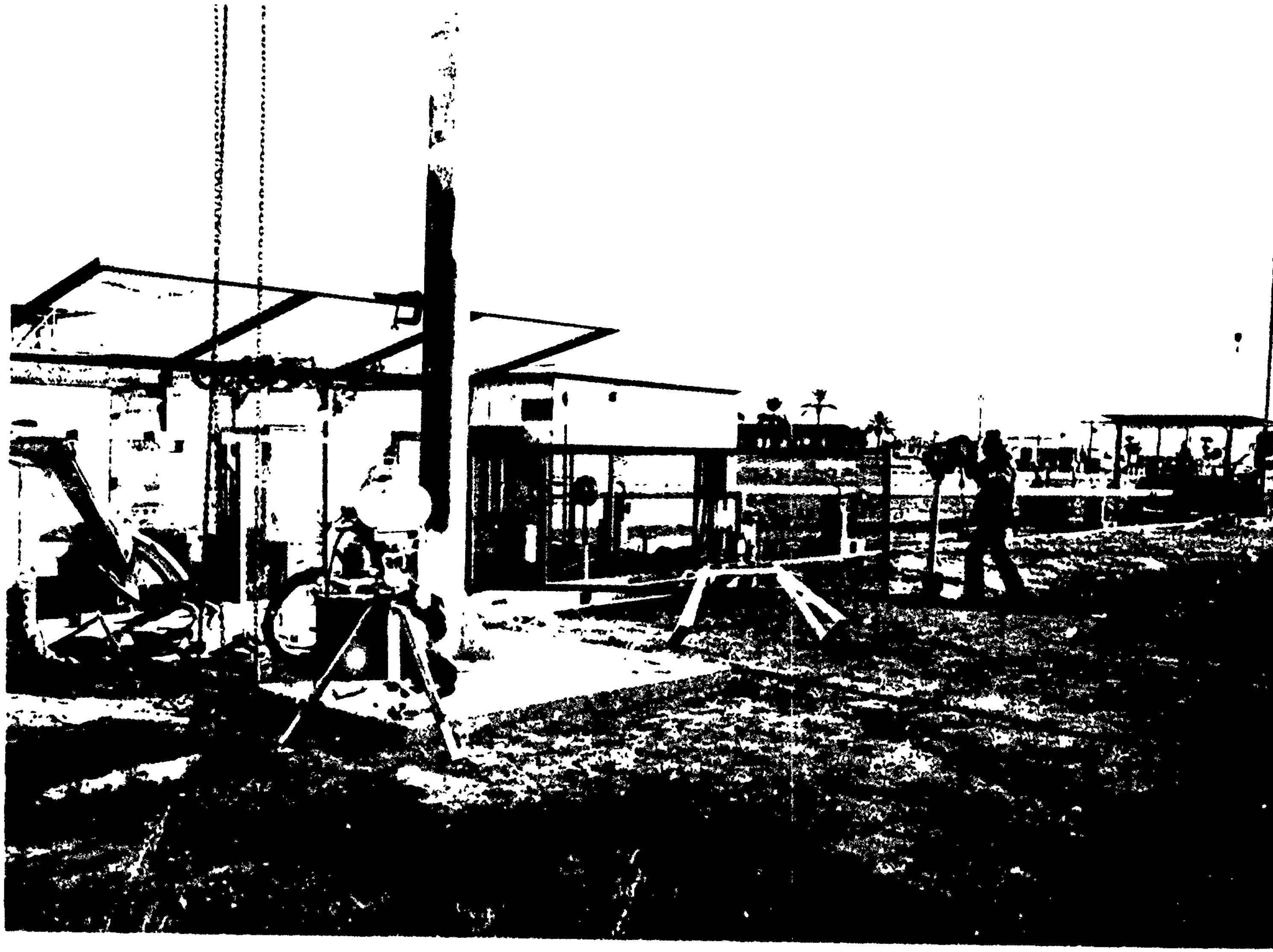


Figure 18 - Bird Impact Test Facility

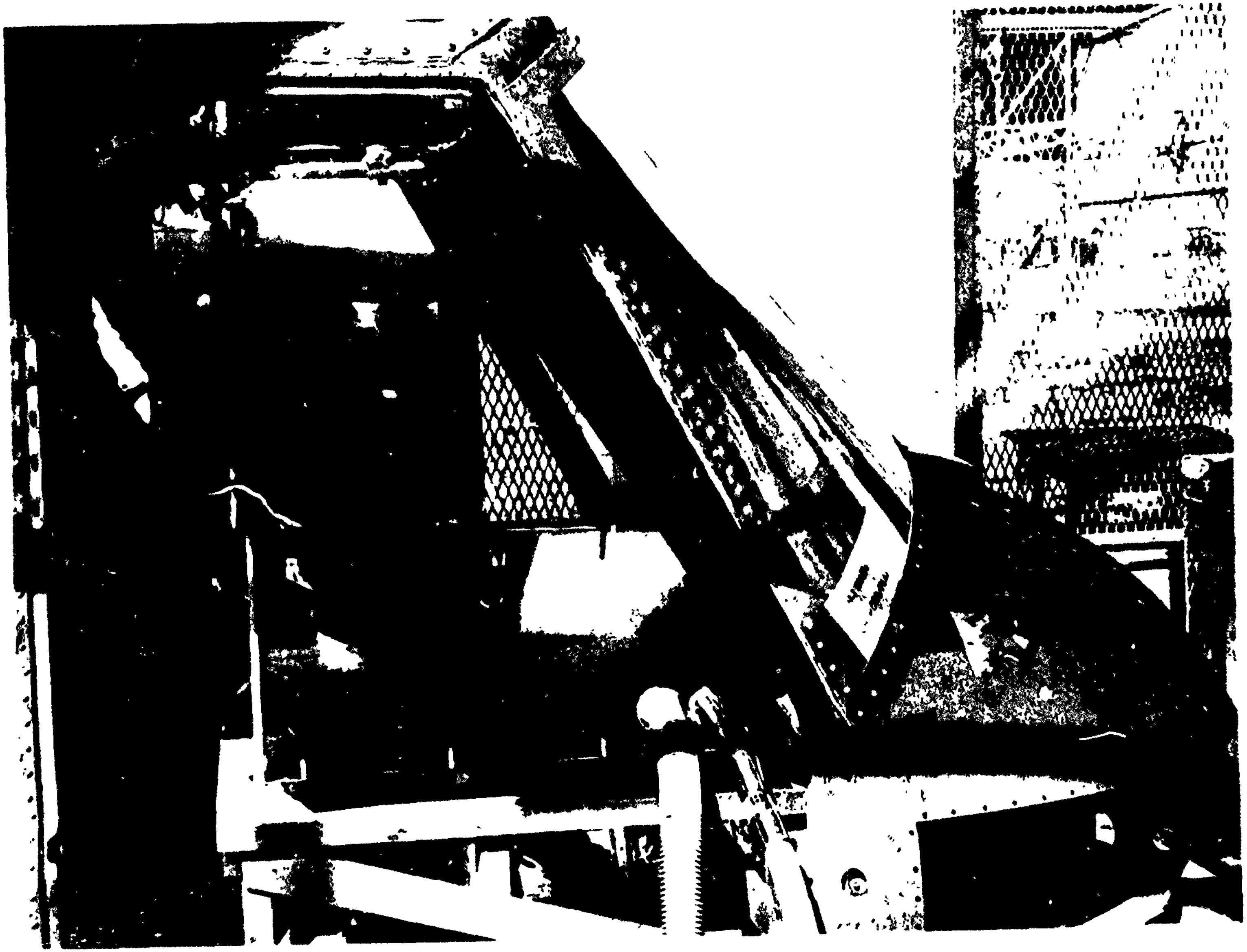


Figure 19 - Bird Impact Test Structure and Pressure Box Detail

## 2. TEST RESULTS

The monolithic polycarbonate windshields were selected as the first test items.

Windshield no. 1 was impacted at 114.5 knots with a four-pound bird. This impact resulted in a diagonal crack running from the upper right-hand corner to the lower left-hand edge of the windshield when viewed from the front (see Figure 20). The bird bounced into the air, and there was no debris in back of the windshield.

Upon close examination of the part, it was noticed that the aircraft structure had bent directly above the spot where the crack terminated. The movies taken confirm the crack initiated in the center of the windshield. The fuselage was bent out into the proper position and readied for the next test.

Monolithic polycarbonate windshield no. 2 was then installed and impacted in the same manner. The impact velocity was 120.8 knots. This impact resulted in several cracks forming and the loss of two pieces of polycarbonate, one in each upper corner of the windshield. The two pieces fell outboard away from the fuselage. A break in the polycarbonate occurred along the upper edge attachment. This edge break permitted the remaining polycarbonate to flex inboard and allowed the bird to deflect upward into the pilot's compartment. The bird hit the top of the pressure box before falling to the floor. The center polycarbonate flexed back into position and was firmly held in place by the lower edge attachment (see Figure 21).

The fuselage again bent inward in the same upper inboard area, and the windshield cracks seemed to initiate from this area.

Standard acrylic windshield no. 1 was then mounted in the fuselage and was impacted with the four-pound bird traveling at 121.9 knots. The bird penetrated the windshield and hit the back of the vacuum chamber. The Plexiglas


Figure 20 - Bird-Impacted UH-1 Polycarbonate Windshield Number 1

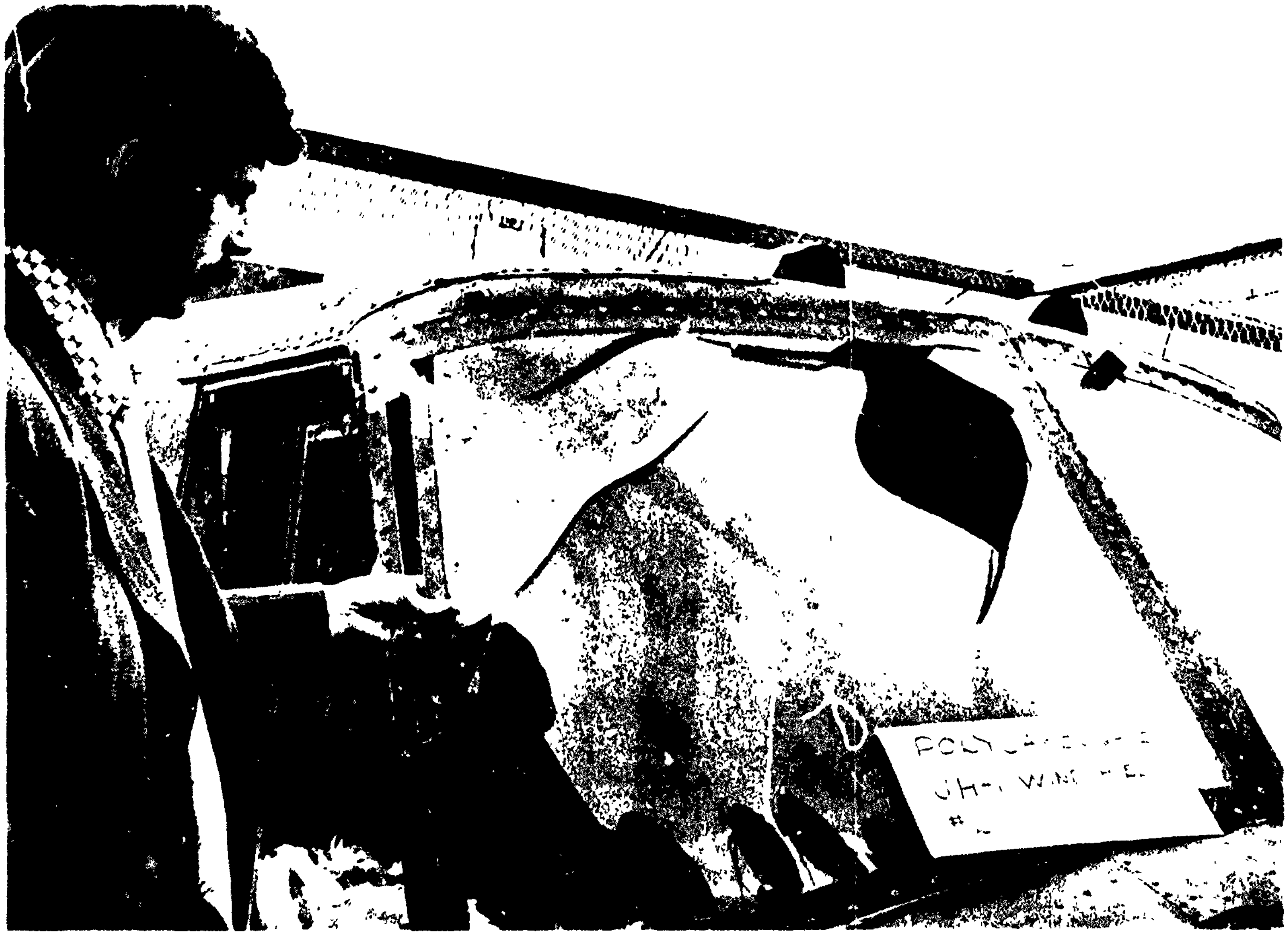


Figure 21 - Bird-Impacted UH-1 Polycarbonate Windshield Number 2

broke out of the frame with only a few jagged fragments remaining along the edge (see Figure 22).

The fuselage was not damaged by the impact.

Because of the catastrophic failure mode of the first standard acrylic windshield, the second standard part was fired at 85.6 knots, which is nearer th cruising speed of the UH-1 aircraft. The bird also penetrated this windshield, breaking out nearly 80 percent of the acrylic (see Figure 23).

The fifth windshield tested was the no. 1 Chemcor-plastic composite. The bird was fired at 115 knots and failed to penetrate the structure. The glass and plastic broke on the lower inboard corner at the edge attachment and bent inward sufficiently to permit small glass particles to enter the lower part of the vacuum chamber (see Figure 24). The bird bounced upward and fell about ten feet from the aircraft.

The second Chemcor-plastic windshield failed in a similar manner at 92.2 knots. No penetration of the bird occurred, but when the composite broke along the lower inboard edging, small spall particles entered the lower part of the vacuum box (see Figure 25). The bird bounced and fell approximately ten feet from the windshield.

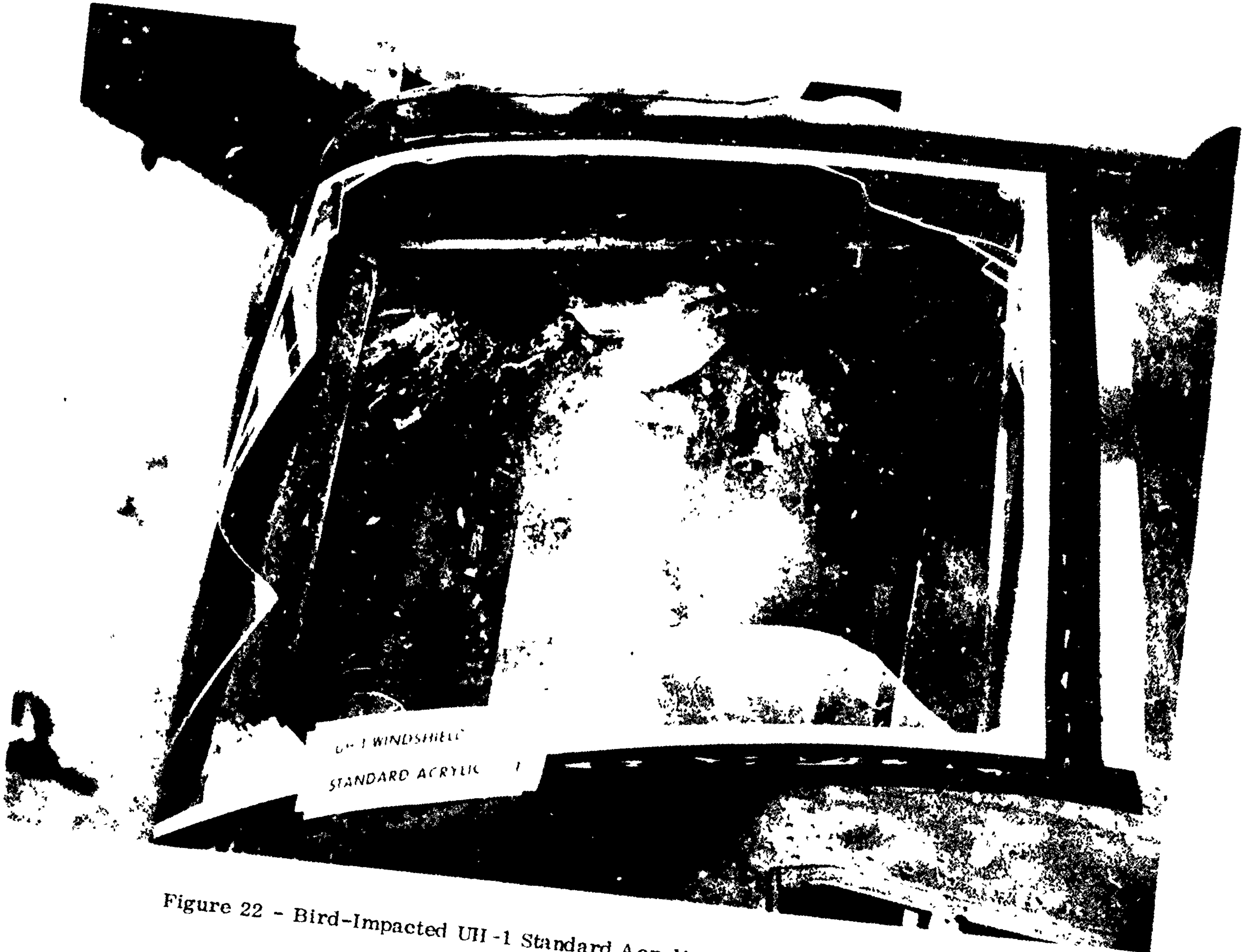



Figure 22 - Bird-Impacted UH-1 Standard Acrylic Windshield Number 1


Figure 23 - Bird-Impacted UH-1 Standard Acrylic Windshield Number 2

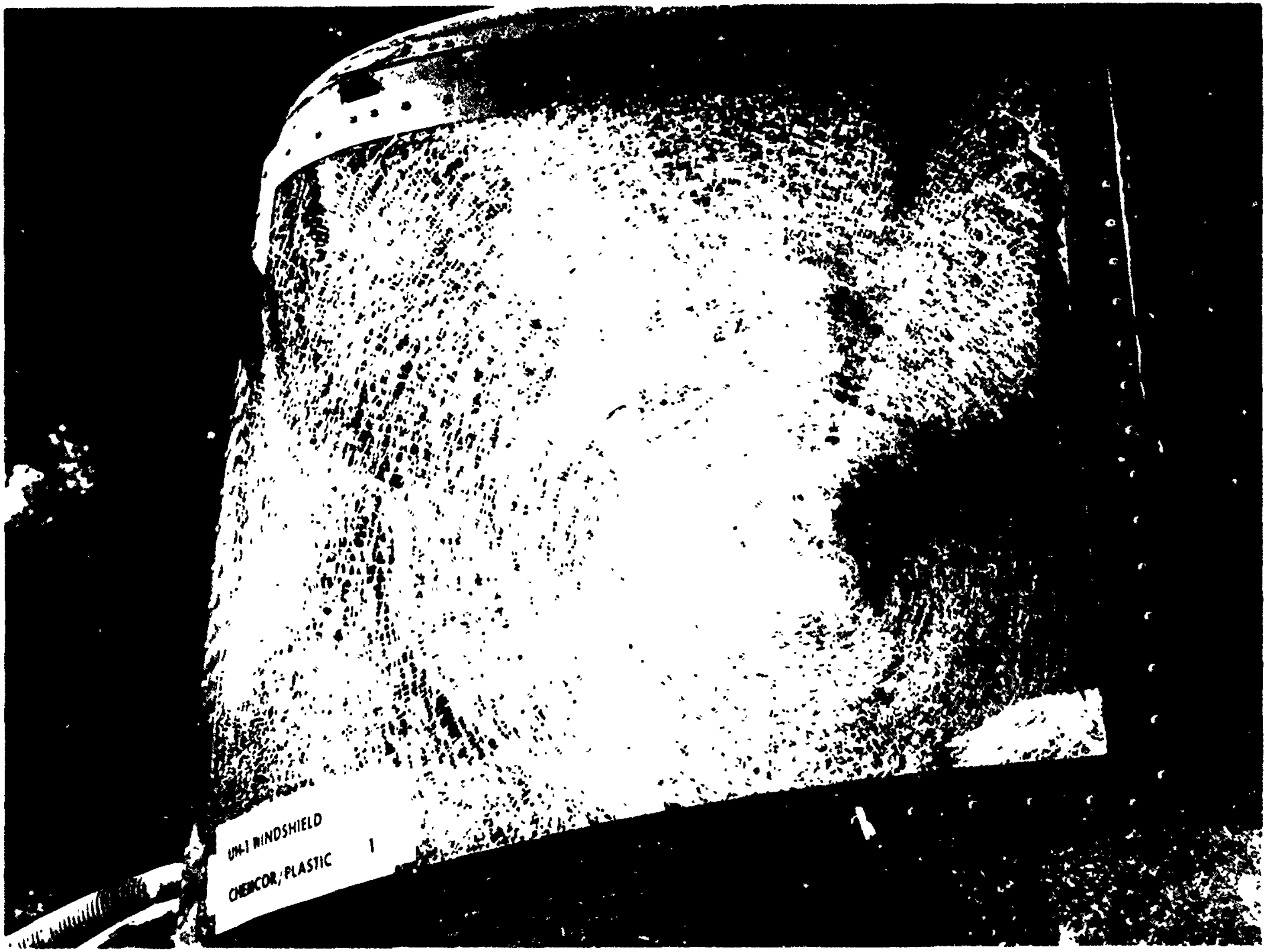



Figure 24 - Bird-Impacted Chemcor-Plastic Windshield Number 1

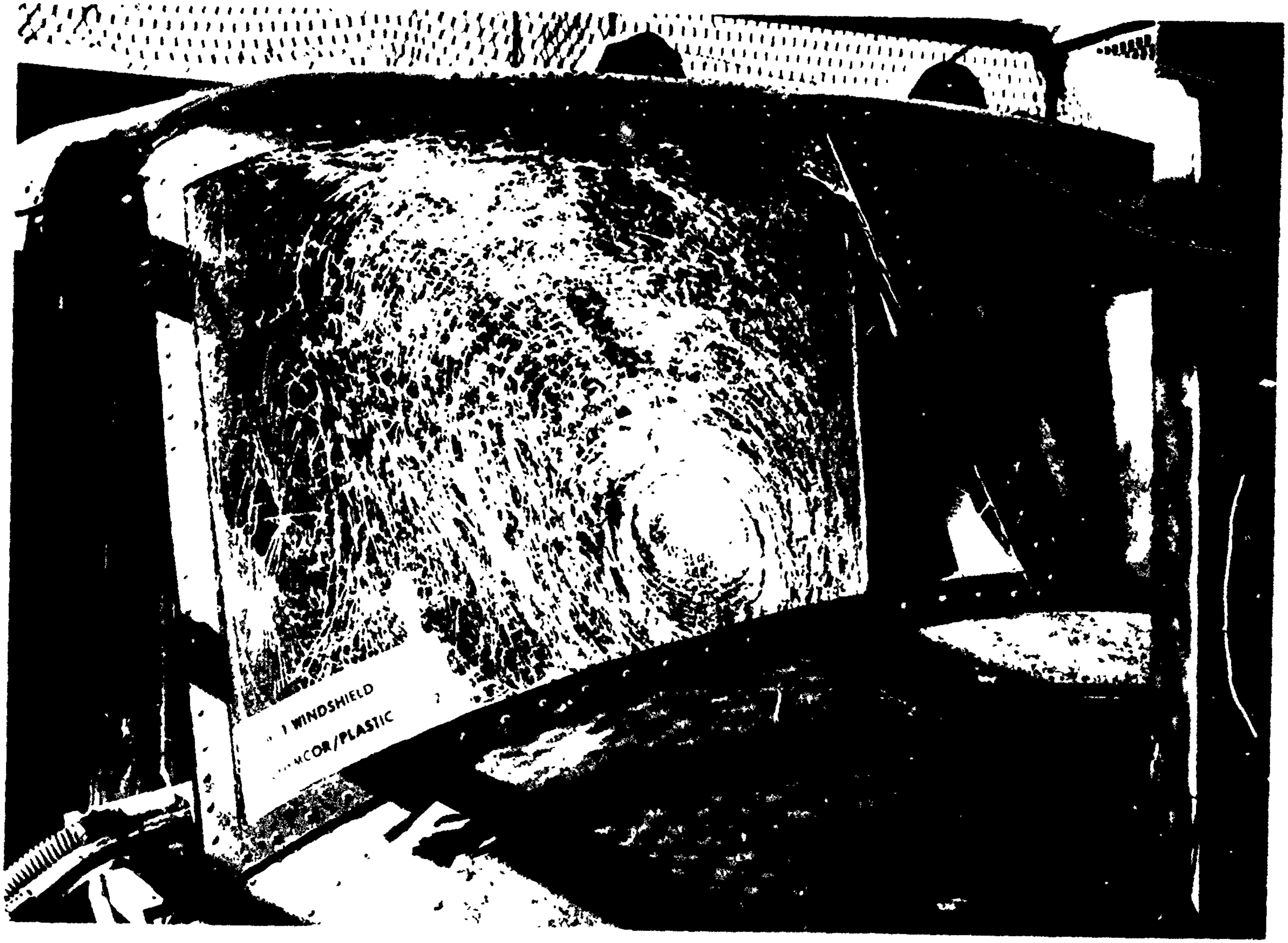



Figure 25 - Bird-Impacted UH-1 Chemcor-Plastic Windshield Number 2

## SECTION IV -

## CONCLUSIONS AND RECOMMENDATIONS

### 1. CONCLUSIONS

Major conclusions from the test program are as follows:

1. Fabrication

   All three types of composites fabricated for this program can be manufactured with currently available materials and state-of-the-art fabrication procedures.

2. Ballistic performance

   a. Ballistic impact of the monolithic polycarbonate windshields shows that very little spall is released and that partial closure of the wound takes place. This construction proved superior in this respect to the other two types tested

   b. Spall from ballistic impact of the standard acrylic windshield results in many widely dispersed, sharp-edged fragments of considerably varying sizes. The spall particles generated did not appear to have potentially lethal penetrating capability.

      The ballistic characteristics of this windshield rank second to those of the monolithic polycarbonate type.

   c. The Chemcor-plastic windshields were the only articles tested which generated spall particles



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having potentially lethal penetrating characteristics. The plastic backing ply acts to restrict the dispersion of the spall, particularly the heavier particles passed. Many very fine glass particles follow the heavier particles in a more widely dispersed cloud. The over. ' spalling characteristics of the Chemcor-plastic windshields were the least acceptable of all windshields tested in this program.

3. Bird Impact Study

a. Both the monolithic polycarbonate with abrasion coating and the Chemcor-plastic composite construction offer far greater bird strike protection to UH-1 aircrews than the standard acrylic windshield.

b. The standard acrylic windshield at both the cruising speed (90 knots) and the maximum speed of the UH-1 is incapable of defeating a bird strike. The as-cast Plexiglas breaks into large, sharp-edged fragments which could cause serious injury to the aircrew.

c. The two monolithic polycarbonate windshields tested indicated they would provide considerable protection against bird strikes, even at redline speed (120 knots) of the UH-1 aircraft. Improved restraint by the edgeband appears necessary to improve bird strike performance.

d. Chemcor-plastic composite offers bird protection from cruising speed (90 knots) to maximum redline speed (120 knots) of the UH-1 aircraft. Some breakage occurred along the edgeband transition of both windshields in the lower inboard corner. The breakage allowed spall to enter the cabin area. A redesign of the edge attachment is needed to withstand the bird strike loading.

## 2. RECOMMENDATIONS

Based on the previous successful field testing of the UH-1 monolithic polycarbonate and Chemcor-plastic windshields, along with the successful conclusion of this program, the following recommendations are submitted:

1. The bird strike information provided during this study offers designers of helicopter transparencies data which will be useful when bird defeat and spall resistance are factors which must be considered.

   However, since the bird strike data obtained on this program are based on very limited testing, it is recommended that additional parts be tested to define more exactly the threshold velocity of each of the monolithic polycarbonate and the Chemcor-plastic windshield designs.

2. It appears that the bird resistance of both the monolithic polycarbonate and the Chemcor-plastic windshield can be improved by a redesign of the edge attachments. The results of the testing to date have emphasized the importance of edge

restraint materials and design in withstanding such loads. Additional bird strike tests should be employed during any redesign effort.

3. Additional bird strike tests should be conducted on the redesigned windshields to document the effect of the following parameters on performance:

    a. Temperature
    b. Outdoor weathering (accelerated exposure)
    c. Bird weight
    d. Effect of strike proximity to edgeband.

4. Test articles of the redesigned windshields should be installed on aircraft for flight testing. This will allow evaluation of the performance and maintainability of the articles in the service environment.